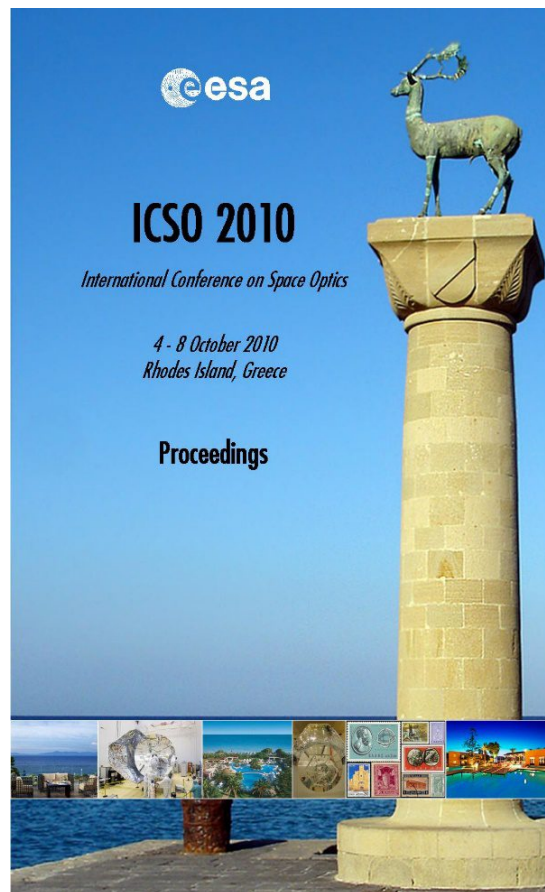


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## *Satellite on-board real-time SAR processor prototype*

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## SATELLITE ON-BOARD REAL-TIME SAR PROCESSOR PROTOTYPE

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### I. INTRODUCTION

A Compact Real-Time Optronic SAR Processor has been successfully developed and tested up to a Technology Readiness Level of 4 (TRL4), the breadboard validation in a laboratory environment. SAR, or Synthetic Aperture Radar, is an active system allowing day and night imaging independent of the cloud coverage of the planet. The SAR raw data is a set of complex data for range and azimuth, which cannot be compressed. Specifically, for planetary missions and unmanned aerial vehicle (UAV) systems with limited communication data rates this is a clear disadvantage.

SAR images are typically processed electronically applying dedicated Fourier transformations. This, however, can also be performed optically in real-time. Originally the first SAR images were optically processed. The optical Fourier processor architecture provides inherent parallel computing capabilities allowing real-time SAR data processing and thus the ability for compression and strongly reduced communication bandwidth requirements for the satellite.

SAR signal return data are in general complex data. Both amplitude and phase must be combined optically in the SAR processor for each range and azimuth pixel. Amplitude and phase are generated by dedicated spatial light modulators and superimposed by an optical relay set-up. The spatial light modulators display the full complex raw data information over a two-dimensional format, one for the azimuth and one for the range. Since the entire signal history is displayed at once, the processor operates in parallel yielding real-time performances, i.e. without resulting bottleneck. Processing of both azimuth and range information is performed in a single pass.

This paper focuses on the onboard capabilities of the compact optical SAR processor prototype that allows in-orbit processing of SAR images. Examples of processed ENVISAT ASAR images are presented. Various SAR processor parameters such as processing capabilities, image quality (point target analysis), weight and size are reviewed.

### 2. BACKGROUND OPTRONIC SAR PROCESSING

Presently, SAR processing is performed digitally using any number of algorithms, such the Range/Doppler, Chirp Scaling or Wavenumber [1].

Each algorithm requires large amounts of computational processing power, largely due to the two-dimensional fast Fourier transforms (FFTs) used. SAR processing can be also seen as a real-time optical demodulation (assuming the Fresnel approximation) and therefore the processing 'algorithms' may be performed with lenses thus providing inherent parallel computing capabilities [2]. Fig. 1 demonstrates the concept behind optical SAR processing that was the original method employed until the 1980s [3].

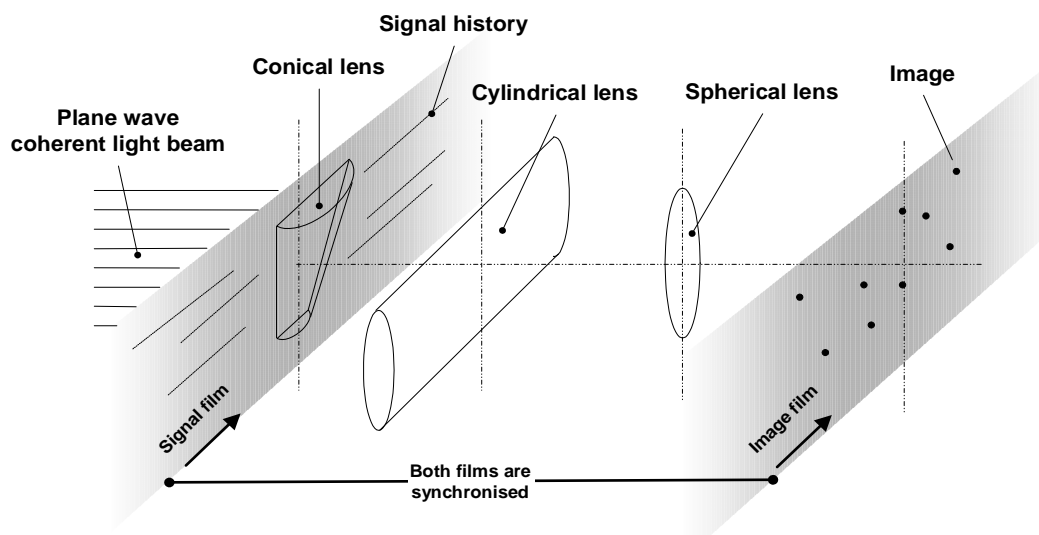


Fig. 1: Original Optical SAR Processing Concept

At that time, the signal film was used for recording the history in the first stage, light from the Cathode Ray Tube (CRT), was used as an input for the processor. The reconstructed SAR image is recorded on another film. Today, the availability of high resolution spatial light modulators (SLM) gives to the optronic processor advantages, such as reprogrammability, that were not available when photographic film was used as the recording medium. An SLM is basically a two-dimensional transmissive electronically addressable display on which images or data can be imaged. The SLM are used as input devices for the SAR raw data

### 3. REAL-TIME ONBOARD PROCESSING CAPABILITIES FOR ONBOARD COMPUTATION

The optronic processor is shown in Fig. 2 and Fig. 3. On the left of Fig. 2, high definition, 1920 x 1080 pixel, spatial light modulators are used to encode complex SAR raw data in amplitude and phase. A CMOS camera, located at the output is also high definition. The processor further comprises various spherical and cylindrical lens elements to perform range and azimuth compression. The processor mass (not optimized) is 6.1 kg and its size is 630 mm x 207 mm x 140 mm (L x H x W). The total power consumption (not optimized) is 15.6 W.

Given specific ASAR system parameters, the total number of points generated per second may be calculated. For a nominal mid-range ENVISAT/ASAR data set (e.g., swath IS4) the generated throughput is calculated to be approximately 10 megasamples/second. From the SAR system parameters, the azimuth and slant range pulse compression ratios are calculated from which the minimum number of frames per second required to process the incoming raw data without bottleneck. The required frames per second for an optical processor employing an SLM with dimensions 1920 x 1080 pixels is deduced to be 59 frames/second. The current prototype frame rate capability is 60 frames/second thus providing real-time processing capabilities. The total processing time for a full ASAR scene of 5200 range samples and 20,000 azimuth lines is 10 seconds.

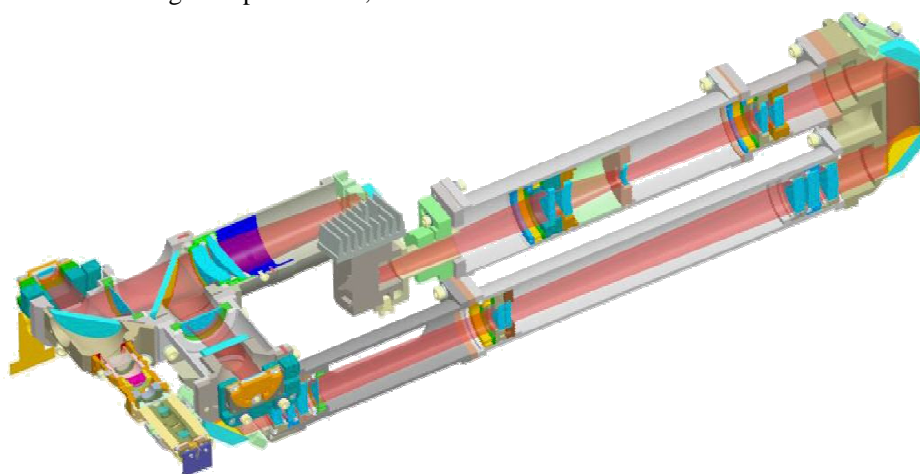


Fig. 2: Optronic SAR Processor layout.

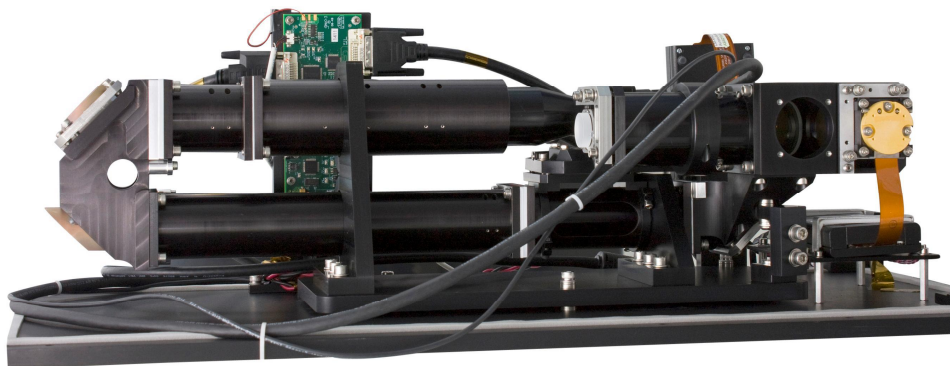


Fig. 3: Optronic SAR Processor

#### 4. ONBOARD PROCESSING BENEFITS

The limitation of remote-sensing SAR systems is that they generate such large volumes of data that the satellite or UAV communications downlink capacity is surpassed.

This means that crucial data that the SAR system could otherwise provide is discarded. This also delays tremendously the access to real-time critical information. An attractive option to increase the data throughput is to compress the SAR raw data. However, the nature of the raw data makes it difficult to compress. The most effective techniques, such as Block Adaptive Quantization (BAQ) result in a compression factor of 4 [4-6]. Another attractive option is to process the SAR raw data onboard. In addition to being smaller in size than the raw data, the SAR images are easier to compress. Table 1 provides a comparison of the compression factors for SAR raw data and images, clearly demonstrating the advantages that on-board processing and compression could provide in terms of the productivity increase of the SAR instrument.

Optronic processors overcome the hurdle for onboard SAR processing that a large volume of raw data must be processed faster than it enters by processing the data in real-time that is, faster than the pulse repetition frequency (PRF). Furthermore, on-board availability of SAR images coupled with automatic signal processing could help select the SAR raw data to be effectively downlinked to the ground station consequently further reducing the quantity of raw data to be sent through the limited available bandwidth.

#### 5. ENVISAT /ASAR IMAGE RESULTS

Point targets were generated to evaluate the quality of the image. The -3dB width, PSLR, and ISLR are shown in Table 2. The table illustrated the excellent performance of the optronic processor compared to predicted values.

ENVISAT / ASAR images from a part of The Netherlands were processed. The swath mode was IS2 and the PRF was 1652 Hz. Fig. 4 shows a section block of the total image and it can be seen that optronically processed image (right) is comparable to final ENVISAT/ASAR image magnitude single-look (IMS) product (left). It can be seen in the figure that the optronically generated image has a finer sampling distance as compared to the IMS product, resulting in improved feature definition as reported in Table 3.

Table 1: SAR Compression Factors

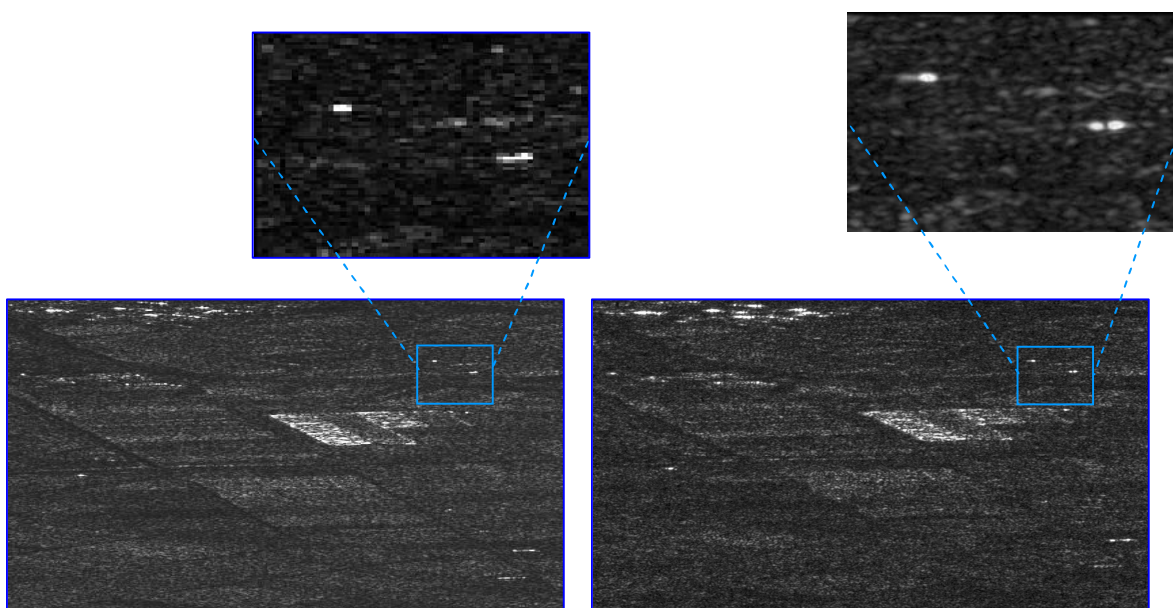
Parameter	SAR Raw Data	SAR Image
Compression Factor	4 X	50 X
Data Processing	None	Multilook Image Processing
Compression Technique	FFT Block Adaptive Quantization	Wavelet Compression
Downlinked Data Format	Complex	Magnitude

**Table 2:** Image quality parameters review

Slant Range						Azimuth						Theoretical	
-3dB Width [pixels]		PSLR [dB]		ISLR [dB]		-3dB Width [pixels]		PSLR [dB]		ISLR [dB]		PSLR [dB]	ISLR [dB]
Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Theory	
3.0	2.9±0.5	-14.1	-10.9±1	-10.0	-8.1±1	5.3	4.8±.5	-13.1	-10.2±1	-8.83	-8.5±1	-13.4	-8.0

**IMS magnitude image**

**Optical magnitude image**



**Fig. 4:** Comparison of Envisat IMS product (right) and optronically processed image using the same raw data.

**Table 3:** Sampling distance

Sampling distance		
<b>Optical Processor</b>	Slant Range	4.2 m
	Azimuth	0.9 m
<b>Digital Processor</b>	Slant Range	7.8 m
	Azimuth	3.7 m

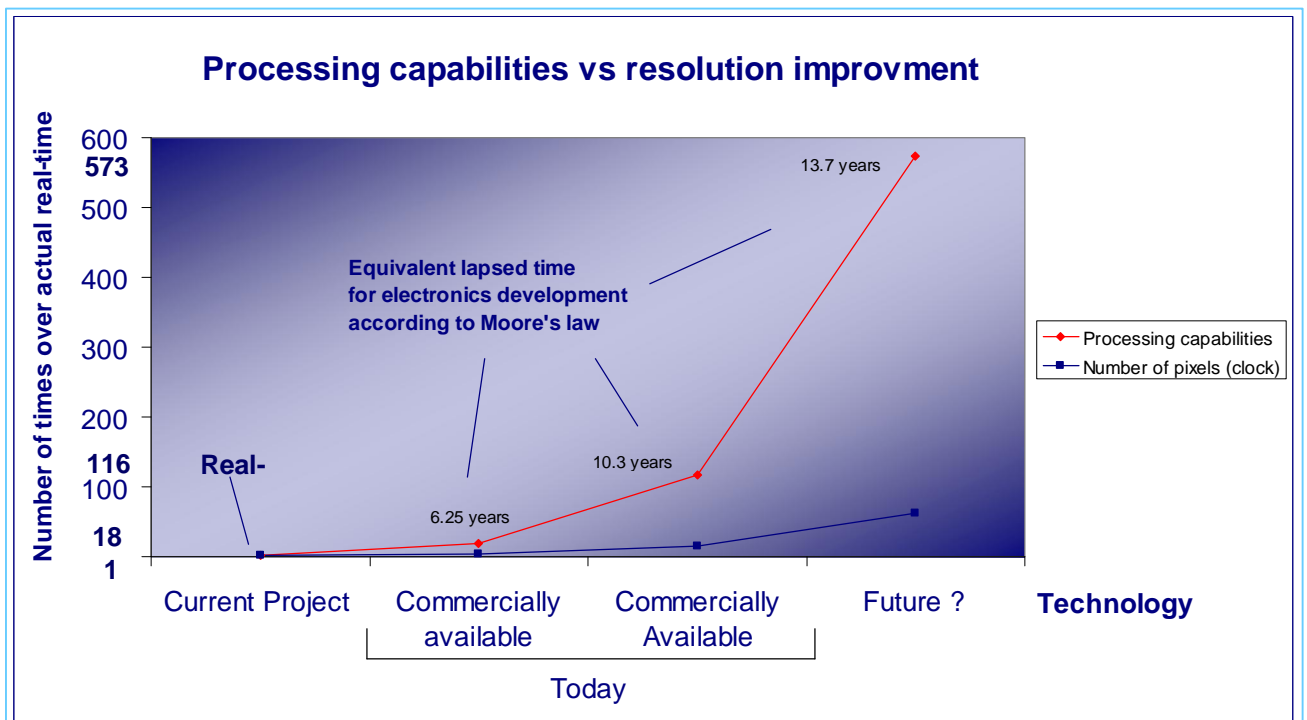
Fig.5 shows a mosaic generated with 5 x 3 section blocks from the same total image. It can be seen that no junctions between the section blocks are visible. This illustrates the very good quality of the optical design used to generate the optronic processor. The adjacent section blocks were simply put aside without any further processing. The mosaicing process was thus, in this case, extremely simple.



**Fig. 5:** Mosaic of 5 x 3 data blocks from ASAR on ENVISAT, over The Netherlands, reconstructed with the optical SAR processor prototype.

## 6. TECHNOLOGY FOR THE FUTURE

Fig. 6 illustrates the current and potential future capabilities of the optronic SAR processor technologies. With current commercially available technology the processor could be made 116 times faster. Considering that the prototype built handles today's throughput in real-time without any bottleneck, these technology improvements offer large potential provisions for future SAR system technology improvement (finer sampling, larger swath, etc).



**Fig. 6:** Current and future potential technology improvements.

## 5. CONCLUSIONS AND FUTURE IMPROVEMENTS

This paper introduces a real-time optronic processor suitable for on-demand SAR image generation. The compact, lightweight prototype has the capability to process high image quality ENVISAT/ASAR images onboard within seconds without bottleneck. The processor shows enhanced sampling distances compared to the IMS product. The near-future processing potential is further estimated to be 116 times the actual real-time capabilities demonstrated, given current commercially available SLMs. Considering that the prototype built handles today's throughput in real-time, these technology improvements allow for near-future optronic processors to handle user demands for finer sampling and larger swath SAR systems.

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